PAPERS AND SHORT REPORTS

Puff volume increases when low-nicotine cigarettes are smoked

RONALD I HERNING, REESE T JONES, JOHN BACHMAN, ALLAN H MINES

Abstract

Variables of smoking were measured when subjects smoked the first cigarette of the day after an eight- to 10-hour period of abstinence. The cigarettes smoked had high, medium, or low nicotine yields but the tar and carbon monoxide yields, taste, and draw characteristics remained constant. The number of puffs and interval between puffs did not differ between nicotine doses. The smokers took larger puffs, however, when smoking cigarettes delivering lower nicotine yields than their normal brands.

This change in the size of puff must be attributed to the change in nicotine yield since all other characteristics of the cigarettes remained constant. Thus encouraging the smoking of low-nicotine cigarettes may increase exposure to combustion products and not appreciably decrease exposure to nicotine, since the smokers increased the size of their puffs in response to the decreased nicotine yield.

Introduction

Tar and nicotine yields of machine-smoked cigarettes have decreased over the past 10 years.[1] The health implications of this change have provoked discussion and confusion among health researchers, policy makers, and smokers.[2] The validity of machine-determined values as predictors of what is actually smoked and even the logic behind the popular low-tar, low-nicotine approach to safer cigarettes have been challenged.[1 3-10] A particular criticism of machine-determined values of nicotine delivery is that smokers may compensate for reduced deliveries by taking more or larger puffs. The cigarettes used in most studies, however, have varied not only in nicotine content but in tar and carbon monoxide yields, flavouring agents, filter types, and size. The period of tobacco deprivation preceding smoking in many of these studies has often been unspecified. It is unclear whether nicotine, some other tobacco constituent, or factors such as taste, draw resistance, and abstinence from smoking produce the smokers' behavioural adjustment.

Precise measurement of smoking behaviour is prerequisite for testing the hypothesis that smokers compensate for reduced nicotine delivery. With few exceptions, the lack of a measure of the actual amount of smoke puffed has impeded testing of the hypothesis.[11 12] Rawbone *et al*[11] reported increased puff volume in smokers who switched from middle-tar to low-tar cigarettes for four weeks. No other measure of puffing or smoking changed. Unfortunately, the cigarette's tar and nicotine yields were not given. Creighton and Lewis[12] reported that people who usually smoked cigarettes yielding 1·4 mg of nicotine increased puff volume and duration when smoking cigarettes delivering 1·0 mg nicotine, while those same smokers reduced puff volume and duration and took fewer puffs with 1·8 mg nicotine cigarettes. Again, however, the tar yields of the low- and high-nicotine cigarettes differed two fold.

Despite the use of cigarettes unmatched for tar content and no measurements of accuracy and reliability of puff volume these studies confirm the importance of measuring puff volume when testing for nicotine compensation.[11 12] We carried out a study in which we varied the nicotine content of cigarettes while holding taste, draw characteristics, and other particulate- and vapour-phase constituents constant.

Subjects and methods

We measured how the first cigarette of the day was smoked after an eight- to 10-hour period of abstinence. Twenty-four regular cigarette smokers (14 men, 10 women; mean age 30 years; mean of 23 cigarettes smoked daily for an average of 13 years) smoked cigarettes identical except for nicotine yield. Table I gives the characteristics of the University of Kentucky alkaloid research cigarettes used in the study.[13] The cigarettes were made from selected tobacco strains that produced various nicotine yields while the tar and carbon monoxide yields remained constant. The subjects did not like the cigarettes

Langley Porter Psychiatric Institute, University of California, San Francisco, California 94143

RONALD I HERNING, PHD, adjunct assistant professor of medical psychology

REESE T JONES, MD, professor of psychiatry, department of psychiatry

JOHN BACHMAN, PHD, clinical psychologist, department of psychiatry, Stanford University School of Medicine

ALLAN H MINES, PHD, associate professor, department of physiology

probably because they were unfiltered and had no flavouring agents as do cigarettes available commercially. Standardised nicotine yield was necessary, however, to test for nicotine compensation. Taste, moisture, and draw characteristics vary between commercial brands so that smoking may possibly alter. Hence the University of Kentucky cigarettes are the only ones available that provide for a fair test.

TABLE I—*Smoking-machine analysis of University of Kentucky alkaloid series cigarettes**

	Nicotine yield		
	Low	Medium	High
Nicotine (mg)	0·4	1·2	2·5
Tar (mg)	31·8	24·5	29·6
Total particulate matter (mg)	35·0	25·7	32·1
Carbon monoxide (mg)	14·9	14·9	16·1
No of smoking-machine puffs	9·2	9·7	9·9
Ratio of tar to nicotine	75·7	19·8	11·8

*Values are based on cigarettes smoked to a 30 mm butt length and are reported by Benner.[13]

On the morning of the three test days the subjects smoked a single cigarette about equal in nicotine yield to their regular brand (that is, 1·2 mg), higher in yield (2·5 mg), or lower in yield (0·4 mg). Order was counterbalanced. Heart rate was recorded continuously. The reported values are those obtained immediately before and five minutes after smoking finished. Breath carbon monoxide concentrations were determined before and 30 minutes after smoking with an Ecolyzer (Series 2000) monitor. A checklist of mood and tobacco symptoms was completed before and after smoking.

Puff volume and duration, number of puffs, and interpuff interval were recorded with an airflow measuring system. A small plastic cigarette holder was attached to a pressure transducer (Statham Model PM5TC) with flexible tubing. The closing of a pressure-sensitive switch in the tubing signalled the start of a puff. Subjects could smoke as they wished but were asked to try to smoke in their usual manner. Butt length was always 30 mm.

In a presmoking calibration procedure air was drawn through each cigarette at 0, 25, 50, 75, and 100 ml/s while the corresponding pressure was determined. Pressure (p) was converted to flow (f) by the derived equation:

$$f = a_1p + a_2p^2 + a_3p^3 + a_4p^4$$

where the a_i are coefficients determined uniquely for each cigarette in the study by non-linear regression. Flow was expressed in ml/s and pressure in analogue to digital converter units. The volume of each puff was determined by numerical integration of the flow values during the puff. Reliability and accuracy were tested by drawing with a glass syringe 20 or 40 ml of smoke through 30 burning cigarettes similar to those smoked by the research subjects. Eleven volumes of smoke were drawn at 5 mm increments beginning at the burning tip and ending 30 mm from the unlit end. Successive volumes had a Spearman Brown reliability coefficient of 0·85. The mean deviation over all draws from our standard (the calibrated glass syringe) was $-0{\cdot}22$ ml with a standard error of $\pm 0{\cdot}32$ ml. The mean deviation and SE from absolute accuracy was $1{\cdot}7 \pm 0{\cdot}8$ ml for the first draw on a cigarette and $-2{\cdot}5 \pm 1{\cdot}0$ ml for the last. Thus a decrease in cigarette length over the range smoked did not significantly alter calculated puff volumes.

Puff duration was timed from the closure of the pressure-sensitive switch at the start of each puff to the return of air-flow values to zero. The interpuff interval was the period of no smoking between puffs. Total smoking time was the time from the start of the first puff to the end of the last puff. Analysis of variance of each dependent variable included tests of the effects contributed by nicotine yield, smoker's sex, and cigarette order.

Results

Puff volume when subjects smoked the low-nicotine cigarette exceeded that when they smoked the medium- or high-nicotine cigarette ($p < 0{\cdot}0001$) (table II). The most commonly reported variables of smoking behaviour, such as number of and interval between puffs, did not differ between nicotine doses.

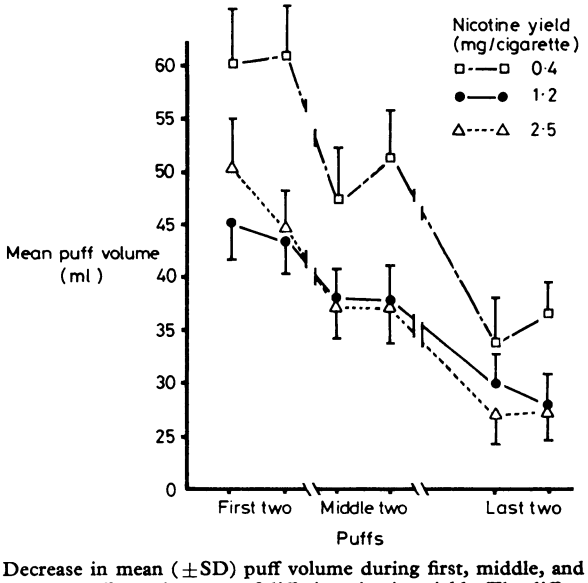
TABLE II—*Mean puff and physiological variables of cigarettes*

Variable	Nicotine yield (mg)			F*	p
	0·4	1·2	2·5		
No of puffs	15·4	15·7	16·8	1·44	NS
Interpuff interval (s)	29·7	26·9	30·0	1·09	NS
Puff duration (s)	2·06	2·06	1·94	0·90	NS
Puff volume (ml)	47·8	35·9	36·9	30·89	<0·0001
Total smoking time (s)	403·8	370·0	446·9	6·50	<0·01
Change in heart rate (beats/min)	12·5	20·3	20·2	18·24	<0·0001
Change in carbon monoxide (ppm)	7·8	7·0	6·1	3·22	<0·05

*F value from analysis of variance for main effect of nicotine yield. Degrees of freedom are 2 and 36.

Subjects took more time to smoke high-nicotine cigarettes ($p < 0{\cdot}05$), and the increase in heart rate was greater with high- and medium-nicotine than with low-nicotine cigarettes ($p < 0{\cdot}001$). The increase in breath carbon monoxide concentration after the subjects had smoked the low-nicotine cigarette was consistent with the increased puff volume with these cigarettes.

The mean volume of the first two puffs (excluding the light-up puff), the middle two, and the last two decreased rapidly for each of the three cigarettes (figure). Puff volume discriminated between the high- and low-nicotine cigarettes almost immediately, suggesting that nicotine delivery is controlled by the smoker from the beginning of smoking with rapid and efficient feedback mechanisms, whatever they may be. No differences between cigarettes in taste or satisfaction derived from smoking were reported. The high-nicotine cigarette made subjects feel more lightheaded and shaky. Satisfaction from smoking was rated as minimal for each cigarette, probably owing to the lack of flavouring agents and dryness of the experimental cigarettes.



Decrease in mean (±SD) puff volume during first, middle, and last two puffs on cigarettes of differing nicotine yields. The differences are significant ($p < 0{\cdot}01$) between puffs and between low-nicotine and medium- and high-nicotine cigarettes.

Discussion

Smokers, even during the first few puffs of a cigarette, adjust the size of puff in response to the nicotine yield when smoking a cigarette with a nicotine yield less than that of their usual brand. Our results were consistent with those of studies using other volume-measuring devices attached to the cigarettes except for interpuff interval and number of puffs.[11 12 14 15] Comer and Creighton[16] noted an increased number of puffs and shorter interpuff interval when the subjects smoked after only one hour of deprivation. The period of deprivation in our study was longer and the number of puffs greater.

In their attempt to adjust smoking behaviour to obtain more

nicotine from low-nicotine cigarettes smokers inhale more of the smoke. The volume of smoke, however, is less than the amount required for perfect titration. The low-nicotine cigarette produced a 33% increase in puff volume and an 11% increase in carbon monoxide concentrations as compared with the medium-dose cigarette, yet represented a 67% decrease in nicotine yield. Thus in our study the smokers, although they increased puff size, were either unable or unwilling to inhale enough smoke to compensate completely for the reduced nicotine yield. Possibly with commercial filtered, flavoured, and moistened cigarettes this would have been less of a problem. What might be considered to be a discrepancy in the percentage increase between puff volume and carbon monoxide concentration in our study must also be interpreted in the light of the study of Ashton *et al*,[17] in which carbon monoxide concentration was found to be a good indicator of chronic plasma nicotine concentration but was not an indicator of nicotine intake from a single cigarette.

Although we studied only the first cigarette of the day and titration was not complete, smokers quickly adjusted their smoking behaviour and the adjustment was based on nicotine content since other characteristics of the cigarettes were held constant. In other studies of titration the nicotine content of the cigarettes covaried with tar content.[11 12] Those studies also found increased puff volume when subjects smoked low-nicotine low-tar cigarettes. There was no extended period of deprivation. In one of the studies[12] a 15% increase in puff volume was observed for a 25% decrease in the delivered dose of nicotine and 31% decrease in tar. These results were based on 10 cigarettes studied over a four-week period. In our study we observed a 33% increase in puff volume with a 67% decrease in nicotine yield while the tar content remained the same. The two studies differed in numerous respects, but in both the percentage increase in puff volume was about half the percentage decrease in the machine-delivered dose of nicotine regardless of the tar content. In the study of Creighton and Lewis[12] a 9% decrease in puff volume was observed for a 25% increase in nicotine and 52% increase in tar yields. In our study no change in puff volume was observed with a 100% increase in nicotine yield and no change in tar yield. Perhaps the 100% increase in nicotine yield was beyond the range at which smokers titrate by puff volume alone. In our study the smokers took 9% longer to smoke this cigarette and experienced more nicotine effects (lightheadedness and shakiness). Hence the smokers must titrate mostly on nicotine delivery rather than on tar or other characteristics of the cigarette.

In the study of Rawbone *et al*[11] the machine-delivered dose of nicotine covaried with the tar content but the machine-delivered dose of tar and other combustion products was not specified. Various commercially available cigarettes appear to have been used. Thus flavourings and draw characteristics of the cigarettes were perhaps not controlled for. A precise comparison of our results or those of Creighton and Lewis[12] with those of Rawbone *et al*[11] is difficult without data on these important factors.

Smoking low-nicotine cigarettes may increase rather than decrease smokers' exposure to carbon monoxide and tar and yet not appreciably decrease their exposure to nicotine. Our results are consistent with Russell's suggestion[18] that less tar and carbon monoxide will be inhaled if cigarettes are manufactured to give medium- or high-nicotine yields but low tar and carbon monoxide yields.

This research was supported in part by grants Nos DA02088 and DA00053 and Programe Project Grant DA01696 from the National Institute on Drug Abuse. We acknowledge the help of Mitzi Speer, Johanna Hunt, and Kaye Welch.

References

[1] Kozlowski LT, Rickert WS, Robinson JC, Grunberg NE. Have tar and nicotine yields of cigarettes changed? *Science* 1980;**209**:1550-1.

[2] Gori GB, Lynch CJ. Toward less hazardous cigarettes. Current advances. *JAMA* 1978;**240**:1255-9.

[3] Ashton H, Watson DW. Puffing frequency and nicotine intake in cigarette smokers. *Br Med J* 1970;iii:679-81.

[4] Frith CD. The effect of varying the nicotine content of cigarettes on human smoking behaviour. *Psychopharmacologia* 1971;**19**:188-92.

[5] Russell MAH, Wilson C, Patel UA, Feyerabend C, Cole PV. Plasma nicotine levels after smoking cigarettes with high, medium, and low nicotine yields. *Br Med J* 1975;ii:414-6.

[6] Forbes WF, Robinson JC, Hanley JA, Colburn HN. Studies on the nicotine exposure of individual smokers. I. Changes in mouth-level exposure to nicotine on switching to lower nicotine cigarettes. *Int J Addict* 1976;**11**:933-50.

[7] Sutton SR, Feyerabend C, Cole PV, Russell MAH. Adjustment of smokers to dilution of tobacco smoke by ventilated cigarette holders. *Clin Pharmacol Ther* 1978;**24**:395-405.

[8] Jarvik ME, Popek P, Schneider NG, Baer-Weiss V, Gritz ER. Can cigarette size and nicotine content influence smoking and puffing rates? *Psychopharmacology (Berlin)* 1978;**58**:303-6.

[9] Ashton H, Stepney R, Thompson JW. Self-titration by cigarette smokers. *Br Med J* 1979;ii:357-60.

[10] Hill P, Marquardt H. Plasma and urine changes after smoking different brands of cigarettes. *Clin Pharmacol Ther* 1980;**27**:652-8.

[11] Rawbone RG, Murphy K, Tate ME, Kane SJ. The analysis of smoking parameters, inhalation and absorption of tobacco smoke in studies of human smoking behaviour. In: Thornton RE, ed. *Smoking behaviour—physiological and psychological influences*. London: Churchill Livingstone, 1978, 171-94.

[12] Creighton DE, Lewis PH. The effect of different cigarettes on human smoking patterns. In: Thornton RE, ed. *Smoking behaviour—physiological and psychological influences*. London: Churchill Livingstone, 1978, 289-300.

[13] Benner JF. Tentative summary of leaf and smoke analysis of the University of Kentucky reference and alkaloid cigarettes. In: Griffith RB, ed. *Proceedings of the Tobacco and Health Conference*. Lexington: University of Kentucky, 1970, 30-2.

[14] Russell MAH, Sutton SR, Feyerabend C, Cole PV. Addiction research unit nicotine titration studies. In: Thornton RE, ed. *Smoking behaviour—physiological and psychological influences*. London: Churchill Livingstone, 1978, 336-48.

[15] Ashton H, Stepney R, Thompson JW. Smoking behaviour and nicotine intake in smokers presented with a "Two-thirds" cigarette. In: Thornton RE, ed. *Smoking behaviour—physiological and psychological influences*. London: Churchill Livingstone, 1978, 315-29.

[16] Comer AK, Creighton DE. The effect of experimental conditions on smoking behaviour. In: Thornton RE, ed. *Smoking behaviour—physiological and psychological influences*. London: Churchill Livingstone, 1978, 76-86.

[17] Ashton H, Stepney R, Thompson JW. Should intake of carbon monoxide be used as a guide to intake of other smoke constituents? *Br Med J* 1981;**282**:10-3.

[18] Russell MAH. Tobacco dependence: is nicotine rewarding or aversive? In: Krasnegor NA, ed. *Cigarette smoking as a dependence process*. Washington DC: US Government Printing Office, 1979, 100-22.

(*Accepted 8 May 1981*)

THE MULBERRY-TREE. This is so well known where it grows, that it needs no description. It bears fruit in the months of July and August.

Mercury rules the tree, therefore are its effects variable as his are. The Mulberry is of different parts; the ripe berries, by reason of their sweetness and slippery moisture, opening the body, and the unripe binding it, especially when they are dried, and then they are good to stay fluxes, lasks, and the abundance of women's courses. The bark of the root kills the broad worms in the body. The juice, or the syrup made of the juice of the berries, helps all inflammations or sores in the mouth, or throat, and palate of the mouth when it is fallen down. The juice of the leaves is a remedy against the biting of serpents, and for those that have taken aconite. The leaves beaten with vinegar, are good to lay on any place that is burnt with fire. A decoction made of the bark and leaves is good to wash the mouth and teeth when they ache. If the root be a little slit or cut, and a small hole made in the ground next thereunto, in the Harvest-time, it will give out a certain juice, which being hardened the next day, is of good use to help the tooth-ache, to dissolve knots, and purge the belly. The leaves of Mulberries are said to stay bleeding at the mouth or nose, or the bleeding of the piles, or of a wound, being bound unto the places. A branch of the tree taken when the moon is at the full, and bound to the wrists of a woman's arm, whose courses come down too much, doth stay them in a short space. (Nicholas Culpeper (1616-54) *The Complete Herbal*, 1850.)